3D FEM dis[illegible]n model of suspended micro channel resonators

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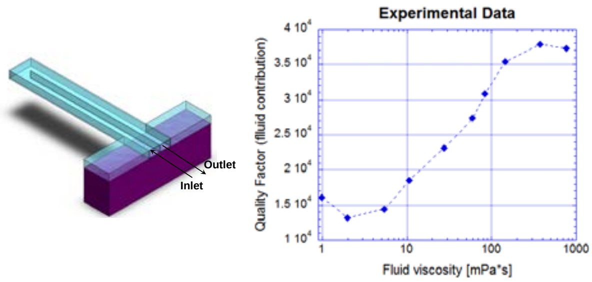
Abstract Suspended micr[illegible]el resonators (SMCs) consist of hollow resonant structures containing an embedded u-shaped micro[illegible]channel. The confinement of the fluid inside the resonator allows real time detection of liquid compou[illegible]ir or in vacuum, while the device quality factor remains almost unaffected. Quality factor of conventi[illegible]tilevers immersed in fluid monotonically decreases as the fluid viscosity increases. On the other h[illegible]Cs exhibit a *non-monotonic* energy dissipation as the fluid viscosity is increased or decreased. In this work we present a fully three dimensional modal analysis of the fluid structure interaction (FSI) problem to predict the quality factor dependence on fluid properties. The reliability of our model is demonstrated through literature comparison of analytical model and experimental results.

Keywords: Biosensors, Suspended microchannel resonator, Microfluidics, Dissipation, Fluid-structure interaction, FEM, ALE

1. Introduction

Nanomechanical resonators have demonstrated great capabilities in life-science label-free sensing applications, such as detection of viruses and single molecules [1]. Frequency stability and high quality factor are both fundamental to optimize the device performances. Operating with biological samples usually involves immersing the resonator in a liquid environment, which yields a deterioration of the device sensing performances due to a coupling between the mechanical resonant structure and the surrounding viscous fluid. This, in turn, decreases the quality factor of the resonator by several orders of magnitude, and also affects its resonance frequency. An alternative approach is the use of suspended microchannel resonators (SMRs) [2], which consist of hollow resonant structures containing an embedded u-shaped micro fluidic channel. The fluid is thus confined inside the resonator, allowing for real time detection of liquid compounds while the device quality factor remains almost unaffected. Quality factors up to 15000 have been demonstrated and a mass sensitivity of 1 attogram (10^{-18} g) in 1 kHz bandwidth has been achieved [3].

In this work we focus on the fluidic contribute to the dissipation of SMRs as a function of fluid properties, in particular viscosity. Theoretical studies and experimental results have shown that these devices present a *non-monotonic* energy dissipation as the fluid viscosity is increased or decreased [4]



a) b)

Fig. 1.a) Schematic of SMCs device. The u-shaped microfluidic channel is embedded in the cantilever. b) Experimental data showing the non-monotonic dependence of the quality factor on the fluid viscosity [4]. Only the fluid contribution is shown.

As shown in Fig. 1.b), the quality factor reverses its trend twice as the viscosity increases, revealing alternating regimes of increasing and decreasing dissipation. This is in contrast with conventional cantilevers immersed in fluid, where the quality factor monotonically decreases as the fluid viscosity increases. The reason of this behavior stems from the shearing of the fluid on the microchannel walls due to inertial effects of the viscous boundary layer at the fluid-solid interface.

2. FEM Model

In order to study the properties of the beam resonator we carry out a fully three dimensional modal analysis of the fluid structure interaction (FSI) problem. We use the Arbitrary Lagrangian Eulerian formulation to tackle the coupled problem and in particular we derive a linearized version of the equations assuming small perturbations. The viscous effects of the fluid are retained in the analysis. Therefore, it is possible to accurately compute the quality factor of the beam from the damping ratio obtained within the modal analysis. The device under exam is a silicon cantilever 210 µm long, 12 µm thick and 33 µm wide. The suspended microfluidic channel, centered on the neutral axis of the resonator, is 8 µm thick and spans the entire length of the cantilever. The quality factor for the first mode of resonance is simulated for several viscous compressible fluids. In order to take into account the contribution of the viscous boundary layer to the damping, a mesh refinement in proximity of the micro-channel walls is performed.

3. Results and discussion

In this paper we investigate the effect of dynamic viscosity on the quality factor of a suspended micro-channel resonator. The reliability of our model is demonstrated through a comparison with theoretical and experimental results found in literature [4, 5]. We vary the viscosity up to 60 mPa·s, taking into account the fluid compressibility.

Our FEM model is in good agreement with experimental data and exhibits a more accurate fit compared to the analytical model already proposed by Sader et al. [4, 5]. In addition, the FEM model allows to predict and calculate not only the resonator quality factor and frequency, but also fluidic properties such as bulk modulus and bulk viscosity.

Future work will be done to complete the validation of the model at higher viscosities, up to 1000 mPa·s. At high viscosity regimes the inertial effects are minimum and the flow induced by the beam oscillation is dominated by the fluid viscous contribute. Also, the viscous boundary layers at the top and the bottom walls of the channel overlap, requiring a finer discretization of the fluidic volume which results in a higher computational cost.

Upon validation across a wider range of viscosities, the FEM model will be used as a tool to investigate the properties of non-newtonian fluids in the MHz frequency range.

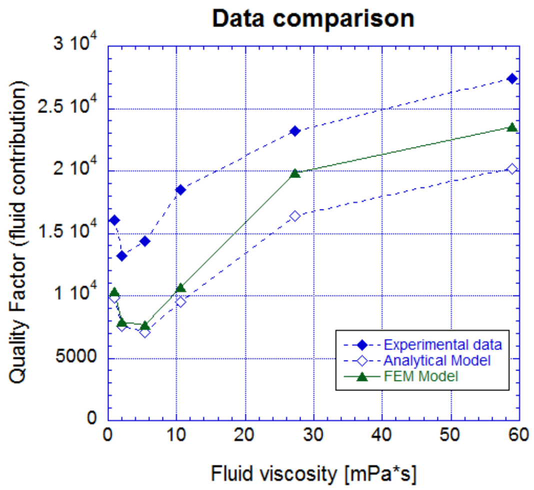


Fig. 2: Comparison between FEM model, experimental measurements and analytical data [4, 5]. The FEM model gives a good prediction of the fluid contribution to the quality factor in function of the fluid viscosity, up to 60 mPa·s.

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